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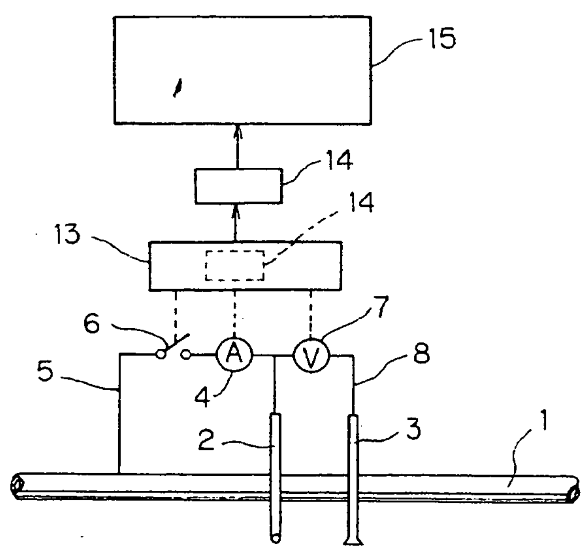
(54) Testing cathodic protection of underground pipelines

(57) To assess the adequacy of a cathodically protected underground pipeline (1) and with consideration for AC corrosion, a steel probe (2) and a copper sulphate reference electrode (3) are installed near the pipeline at depth. The steel probe (2) is electrically connected to the pipeline and the measurements of AC probe currents flowing between a steel probe (2) and a pipeline (1) are carried out simultaneously together with those of on- and off-potentials, and DC probe currents.

Fig.1



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Description

This invention relates to a method of testing and evaluation, as well as apparatus and instrumentation, using steel probes and for the cathodic protection of underground pipelines.

It is known that the adequacy of an underground pipeline cathodic protection system is assessed by measuring potential and current of a steel probe placed near the pipeline at depth, that is under the same environmental conditions. A saturated copper/copper sulphate reference electrode (CSE) is also installed in the vicinity of the steel probe. The steel probe, simulating a coating defect, is electrically connected to a pipeline. Off-potential without IR-drop is measured with respect to a CSE by interrupting the steel probe and a pipeline connection. Recently, this method termed instant-off method has been widely used to assess cathodic protection conditions.

Referring to the drawings, introduced later herein, and specifically to Figure 10, a schematic of the method for measuring pipe-to-soil potential with a steel probe is shown. In Figure 10,1 is a pipeline, 2 a steel probe, 3 a CSE, 4 an ammeter in line 5 between a pipeline and a steel probe, 6 an on/off switch, 7 a voltmeter in line 8 between the steel probe 3 and CSE 4, 9 an electrode for cathodic protection, 10 an anode, 11 a sacrificial anode, and 12 a recorder.

In the above mentioned system, the adequacy of cathodic protection is assessed by measuring on-potential (pipe-to-soil) potential, off-potential, and current density. On-potential and current density are simultaneously obtained before interruption of the steel probe and a pipeline. Off-potential is obtained after disconnection of the steel probe and pipeline intervals of 0.6 to 1.0 sec. in every 10 to 20 sec. by using an on/off switch 6. Time variations of on-potential, off-potential, and current density are recorded using a recorder 12. An example of the output data by a field study is shown in Figure 11.

However, some disadvantages regarding the above mentioned method arise as follows:

a) Original waveforms regarding on- and off-potentials, and probe currents are not obtained due to the use of a recorder with lowpass filter.

b) Off-potentials, DC and AC probe current densities are indispensable to assess the adequacy of cathodic protection. However, in the conventional method, off-potential of the steel probe is not accurately taken after disconnection of the steel probe and a pipe, when a significant problem with depolarisation is observed. Additionally, effective frequency in AC probe current density is not gained.

c) It is impossible to calculate data when the time averaged values are required, for example. because digital on-off-potentials, and DC and AC probe current densities are not acquired in the system.

To overcome the above mentioned issues (a) to (c), there has been proposed in Japanese Patent Application JP 8-345313A an evaluation method for cathodic protection of underground pipelines using a steel probe and a CSE near the pipeline at depth, by numerically analysing on- and off-potentials, and probe currents that are collected using a computer. The steel probe is electrically connected to a pipeline. Frequency analysis of collected data is performed, then levels of on- and off-potentials, and probe currents at effective frequencies are assessed.

Recently, buried pipelines tend to run parallel to electric transmission lines or railways. In such a case, a powerful magnetic field is generated between a pipeline and ground and a considerable voltage may be induced particularly in a well coated pipeline. The above mentioned patent does not directly refer to data regarding AC corrosion.

On the other hand, the present situation is that the buried environment of pipelines is becoming more and more aggressive and the opportunities for AC corrosion are being expanded.

According to this invention there is provided a method for testing or assessing the adequacy of a pipeline cathodic protection using a steel probe and a reference electrode (CSE) installed at depth near the pipeline, the steel probe being electrically connected to the pipeline, characterised in that the measurement of AC probe currents flowing between the steel probe and pipeline are carried out simultaneously together with those of on- and off-potentials and DC probe current densities.

The present invention is characterised in such a way that it provides an AC corrosion counter-measure by burying the steel probe and a CSE adjacent to the cathodically protected pipeline and measuring simultaneously on- and off-potential between the above mentioned steel probe and a CSE and DC between the steel probe and the pipeline, and further by measuring the value of an AC between the steel probe and the pipeline in synchronism with this measurement timing when evaluating the corrosion level from these values and evaluating AC corrosion level from these values.

This invention is further described and illustrated with reference to the drawings, wherein:

Figure 1	shows a diagram of a single test station of this invention,
Figure 2	shows a schematic representation of measuring time of on-potential, off-potential and probe current,
Figure 3	shows an explanatory diagram of display and calculation of on- and off-potentials,
Figure 4	shows the behaviour of potential and current,
Figure 5	shows an explanatory view of an original waveform of on-potential,

Figure 6 shows the behaviour of on-potential and frequency spectrum,
Figure 7 shows an example of probe current,
Figure 8 shows a block diagram of an apparatus according to this invention,
Figure 9 shows an explanatory drawing of the measurement method of this invention,
Figure 10 shows an explanatory diagram of a known cathode protection arrangement, and
Figure 11 shows an explanatory diagram of the cathode protection data obtained from Figure 10.

Referring to the drawings, Figure 1 shows a cathode protection unit relating to this invention, wherein 1 is a pipeline, 2 a steel probe, 3 a CSE, 4 an ammeter inserted into the line 5 connecting between the pipeline 1 and the probe 2, 6 is an ON/OFF switch and 7 an ammeter inserted into the line connecting between the probe 2 and the electrode 3. For clarity a DC power source for cathodic protection, anode and sacrifice anode are omitted. In Figure 1, 13 is a cathodic protection monitor, and an IC card as a recording means (85 MB) 14 for recording the data is incorporated into this monitor 13, and stores the on- and off-potentials and probe current. The IC card 14 is connected with computer 15 for analysing the data obtained.

Hereinafter, the acquisition of data and the analysis of the numerical data is conducted using the computer 15 which is now explained.

Cathode Protection Data Measurement & Analysis

As shown in Figure 2, the measurement is taken for the data around the point of time when the probe 2 has changed from ON to OFF at all times. Generally, the ON time is very much longer than the OFF time, and basically the one cycle is set to 10s (seconds) with the ON time being 8.5s and the OFF time being 1.5s. For example, if the measurement time is over, or for, 2 minutes, it means that 1 cycle has been repeated. Basically, the time before OFF time and the time after the OFF time is set to 1s. The range within the time before OFF and the time after OFF is sampled every 0.1 ms for taking and capture of values of on-potential, off-potential and probe current as accurately as possible. Therefore, the amount of data for on-potential, off-potential and probe current becomes voluminous with as many as 120,000 data items recorded.

1) Display of on-potential.

Within the range of time before the preset OFF, the on-potential to the measuring instrument is displayed and calculated (maximum value, minimum value and averaged value). Empirically, the range from 0.3s before OFF and 0.2s is optimum for the display and calculation of on-potential (see Figure 3). Therefore, because the time range of this 0.1s is being sampled at every 0.1 ms at one cycle, the total number of samplings becomes 1,000, and the maximum value, minimum value and averaged value in the 1,000 data are to be displayed.

2) Display of off-potential.

Within the range of time after the preset OFF, the OFF potential to the measuring instrument is to be displayed and calculated. Theoretically, the off-potential is the probe potential subtracting the IR (mainly the protective current and soil resistance) immediately after the OFF, but because empirically an abnormal current signal is entered in many cases immediately after the OFF, the evaluation shall be made between time range from 0 2s to 0.3s after the OFF. This becomes identical to the calculation of on-potential, which is to display the maximum value, minimum value and averaged value in 1,000 data at one cycle.

3) Display of probe current.

Because the probe current is to be evaluated under the ON status, it becomes identical to the measurement of on-potential.

The displays of said on- and off-potentials and probe current can be optionally set so long as the range is within the time before OFF and the time after OFF.

Software and Output

For example, the measurement conditions are set as follows, these being standard.

ON time	8.5s

(continued)

OFF time	1.5s
1 cycle	10s
Measurement time	120s
Time before OFF	1s
Time after OFF	1s
On-potential display measuring range	0.3 to 0.2s before OFF
Off-potential display measuring range	0.2 to 0.3s after OFF
Data sampling interval	0.1ms

Then, because the time before OFF and the time after OFF are identical to each other, twelve cycles can be obtained as the output as the embodiment in Figure 4 shows with the OFF time between the probe 2 and the pipeline 1 as target. The reason why each cycle is intermittent is because the continuous measurement is actually being conducted. The maximum value, minimum value and averaged value of on- off-potentials and probe current within the preset range are displayed to the right side of Figure 4.

The sampling interval is set to 0.1 ms due to the following two reasons:

1) By capturing the original waveforms of on-potential and probe current when the steel probe is electrically connected to a pipeline, the cause of fluctuation can be specified in the frequency analysis, and moreover, evaluation of the adequacy of cathodic protection is performed by the analysis of the original waveforms of on-potentials and probe currents. Figure 5 is an explanatory view of original waveform of on-potential while Figure 6 displays a spectrum analysis of on-potential by the FFT (Fast Fourier Transformation). Effectively only the 50Hz component of the power-line frequency remains indicating the inductance of electric power transmission lines. What relates to the corrosion is the low frequency constituent from the probe current taken at the same time with the on-potential.

In the present embodiment, the filter used for the FFT bases on the original wave form taken in 0.1 ms calculates and displays the averaged value of each constituent of 25 Hz, 50 Hz, 100 Hz, 200 HZ and 500 Hz. Figure 7 shows these embodiments.

2) Probe off-potential must be determined on the basis of the analysis of original potential waveform. This is the reason why the data sampling time 0.1 ms is required.

If the standard has not been satisfied in comparison with the following cathodic protection criteria as a result of analysing the numerical value, the disposal for decreasing AC voltage should be taken by lowering AC voltage of pipeline and by connecting the low earth substance to the pipeline. It is probable that the electromagnetic induction voltage is generated in the pipeline and AC corrosion may be induced.

Criteria for cathodic protection using instant-off method with steel probes.

1. Under conditions without induced AF voltage

(a) at least-1.0 V CSE off-potential, or
(b) at least 0.010 mA/cm^2 DC probe current density.

2. Under conditions with induced AC voltage

Criteria for cathodic protection conditions with induced AC voltage have not yet been established. That is, the relationship between off-potential, DC probe cathodic current density, and AC probe current density is not well understood in order to prevent AC corrosion. However, proof that the corrosion rate is suppressed below 0.010 mm/y has been obtained, when AC probe current density is lower than $5mA/cm^2$. Because of this situation, the tentative criteria for cathodic protection are set forth; that is the above mentioned (1) and lower than $5mA/cm^2$ averaged AC probe current density.

The present invention is to assess the adequacy of cathodic protection by evaluating DC components (on-potential, off-potential, and DC probe current density) together with AC probe current density.

This method is expounded on the basis of Figure 8. In Figure 8, 1 is a pipeline, 2 a steel probe, 3 a CSE, 6 an ON/OFF switch, 16 a protective circuit, 17 a band pass filter, 18 a low pass filter, 19 an amplifier, 20 a measurement circuit, 20a an OFF current (the effective value from 50 to 60 HZ zone) measuring portion, 20b is an ON current (the filter is ON at all times) measuring portion, 20c is an off-potential (the filter is OFF at all times) measuring portion, 20d is an

on-potential (the filter is ON at all times) measuring portion, 21 is a data processing portion, 22 is a recording portion, 23 is an LCD display, 24 is a control portion (keyboard) and 25 is a power source.

In this instrumentation, after the disconnection of the steel probe and a pipeline, potential data are collected at the sampling time of 0.1 ms without lowpass and bandpass filters. The reason why the presented procedures are taken is because (1) the potential fluctuations of steel probe 2 are induced (it is assumed that the reason why there is a potential fluctuation is because the steel probe 2 is in a strong electromagnetic field) although the level of AC induction voltage is low even after the OFF under overhead high voltage electric wire, and (2) there is the need for capture of the original waveform since there is the depolarisation phenomenon of steel probe 2 after the OFF (the phenomenon where the steel probe 2 shifts in a higher direction.

Figure 9 shows an explanatory view of the measurement method for estimating AC corrosion level with a steel probe interrupted at a cycle of 8.5-second on and 0.5-second off by using an ON/OFF switch 6, which is repeated for 120 seconds.

During this ON/OFF state, the maximum value, minimum value and averaged value of probe on-potential and DC probe current is measured with the low pass filter 18 (cut-off frequency of 50 HZ) ON, and moreover the rms current of probe AC 50/60 HZ shall be measured with the band pass filter 17 ON, and further the probe off-potential (the averaged value of 0.1 ms sample data) shall be measured with the filter being OFF.

Symbol "A" in Figure 9 is the maximum, minimum and averaged value measurement (the probe rms current of on-potential, DC 50/60 Hz), and Symbol "B" is the averaged value of 0.1 ms sample data, whose start and end can be freely set in the control portion 24.

The said matter was measured 90 cycles for 15 minutes for both the "A" and "B" cases at a test station.

For information, the timing of 8.5 seconds for ON time and 1.5 seconds for OFF time is to avoid disturbing the influence of electric iron operation against the pipeline 1 (from the study result in the field thus far). However, in the case of overhead electric power transmission lines, on-and off-time does not have a significant meaning due to repeatable phenomena.

As described above, the present invention enables an engineer to evaluate the effect of induced AC voltage on a pipeline paralleling an electric power transmission line or a railway. Thereby, the pipeline integrity for cathodic protection will be ensured.

Claims

1. Method for testing or assessing the adequacy of a pipeline cathodic protection using a steel probe (2) and a reference electrode (CSE) installed at depth near the pipeline (1), the steel probe (2) being electrically connected to the pipeline (1), characterised in that the measurement of AC probe currents flowing between the steel probe (2) and pipeline (1) are carried out simultaneously together with those of on-and off-potentials and DC probe current densities.

2. Method in accordance with Claim 1, characterised in that a steel probe measures DC and AC probe current densities and probe off-potentials simultaneously.

3. Method in accordance with Claim 1 or 2, characterised in that DC probe current densities are obtained using a low pass filter, AC probe current densities are obtained using a bandpass filter, off-potential is obtained by averaging potential data collected at a constant interval after disconnection of the steel probe and a pipeline.

4. Method in accordance with any preceding claim, characterised in that for 50 Hz induced frequency, off-potentials are obtained by averaging potential data collected at intervals of 0.1 ms from 10 ms to 30 ms after disconnection of the steel probe and a pipeline.

5. Method in accordance with any preceding claim, characterised in that for 60 Hz of induced frequency, off-potentials are obtained by averaging potential data collected at intervals of 0.1 ms from 10 ms to 26.7 ms after disconnection of the steel probe and a pipeline.

6. Apparatus for testing or assessing the adequacy of a pipeline cathodic protection using steel probes (2) for cathodic protection of underground pipelines (1) characterised by a steel probe and a CSE being installed near the pipeline at depth, the steel probe being electrically connected to the pipeline, the measurements of AC probe currents flowing between the steel probe and the pipeline being carried out simultaneously with those of the on- and off-potentials and DC probe currents.

Fig.1

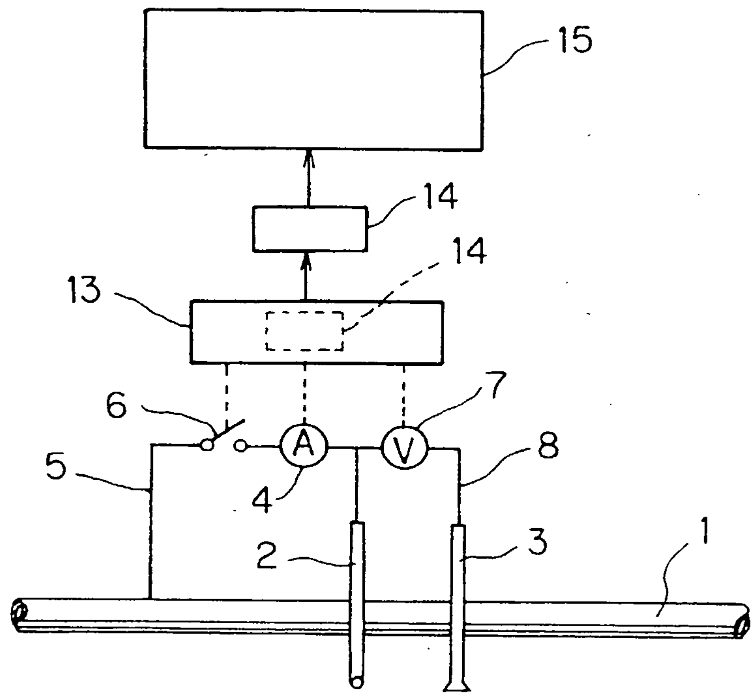


Fig.2

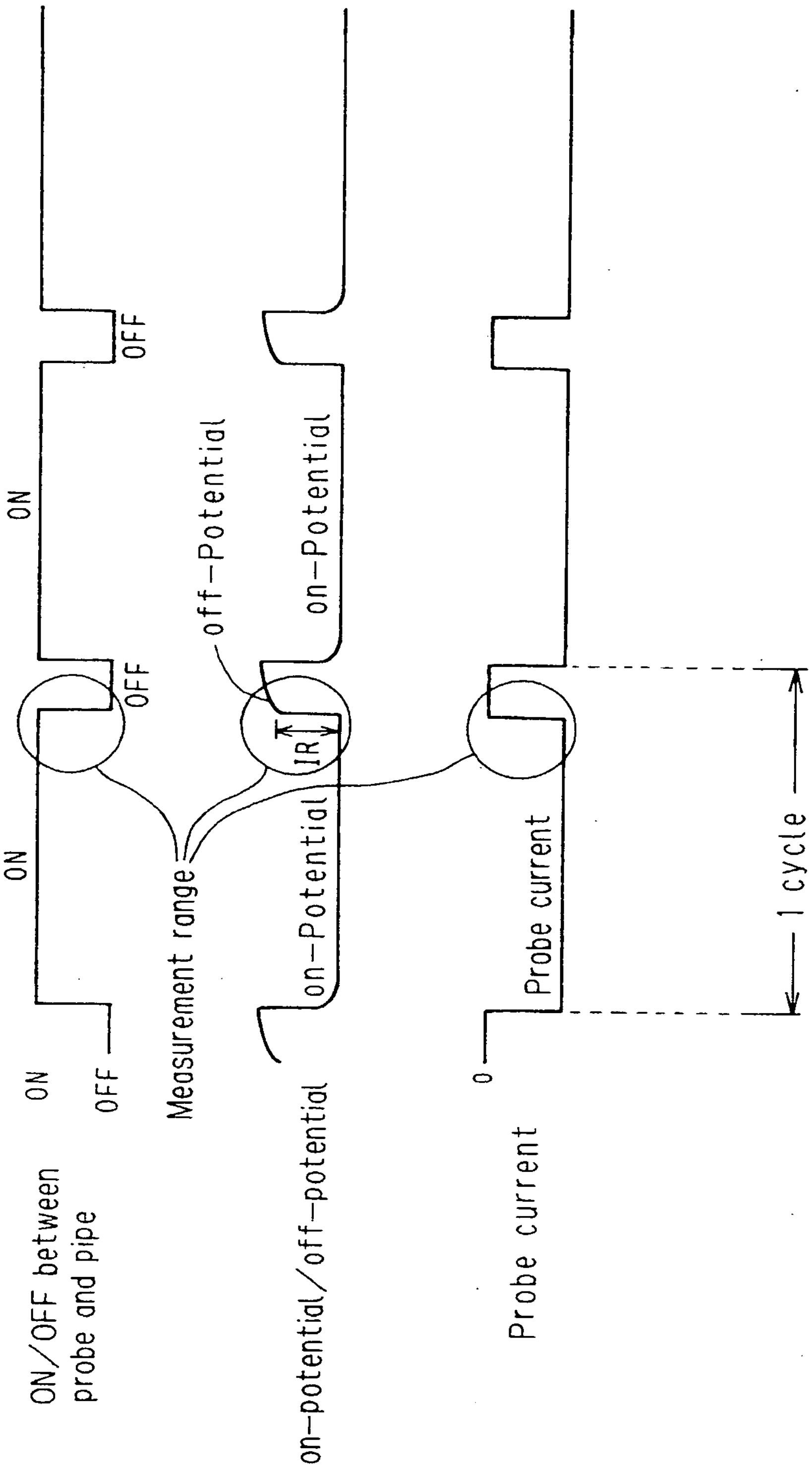
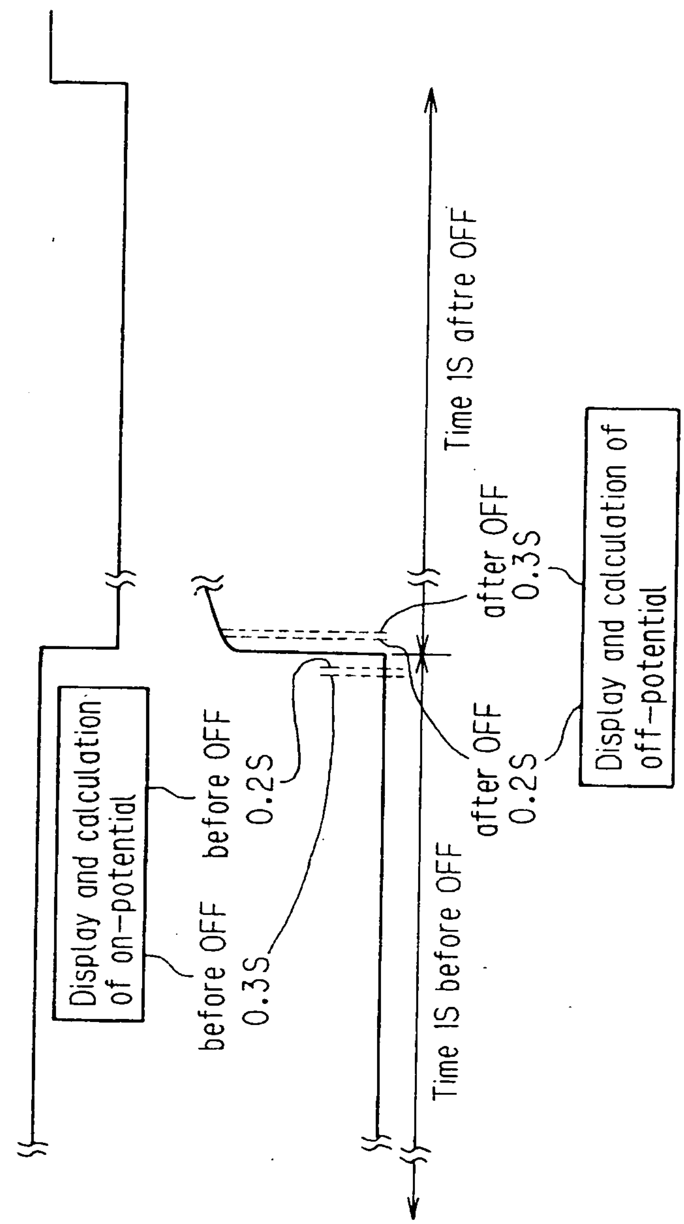

ON/OFF between probe and pipe
ON
OFF
ON
OFF
ON
OFF
Measurement range
off-Potential
on-potential/off-potential
on-Potential
on-Potential
IR
Probe current
0
Probe current
1 cycle

Fig.3


Display and calculation of on-potential
before OFF 0.3S
before OFF 0.2S
after OFF 0.2S
after OFF 0.3S
Display and calculation of off-potential
Time 1S before OFF
Time 1S aftre OFF

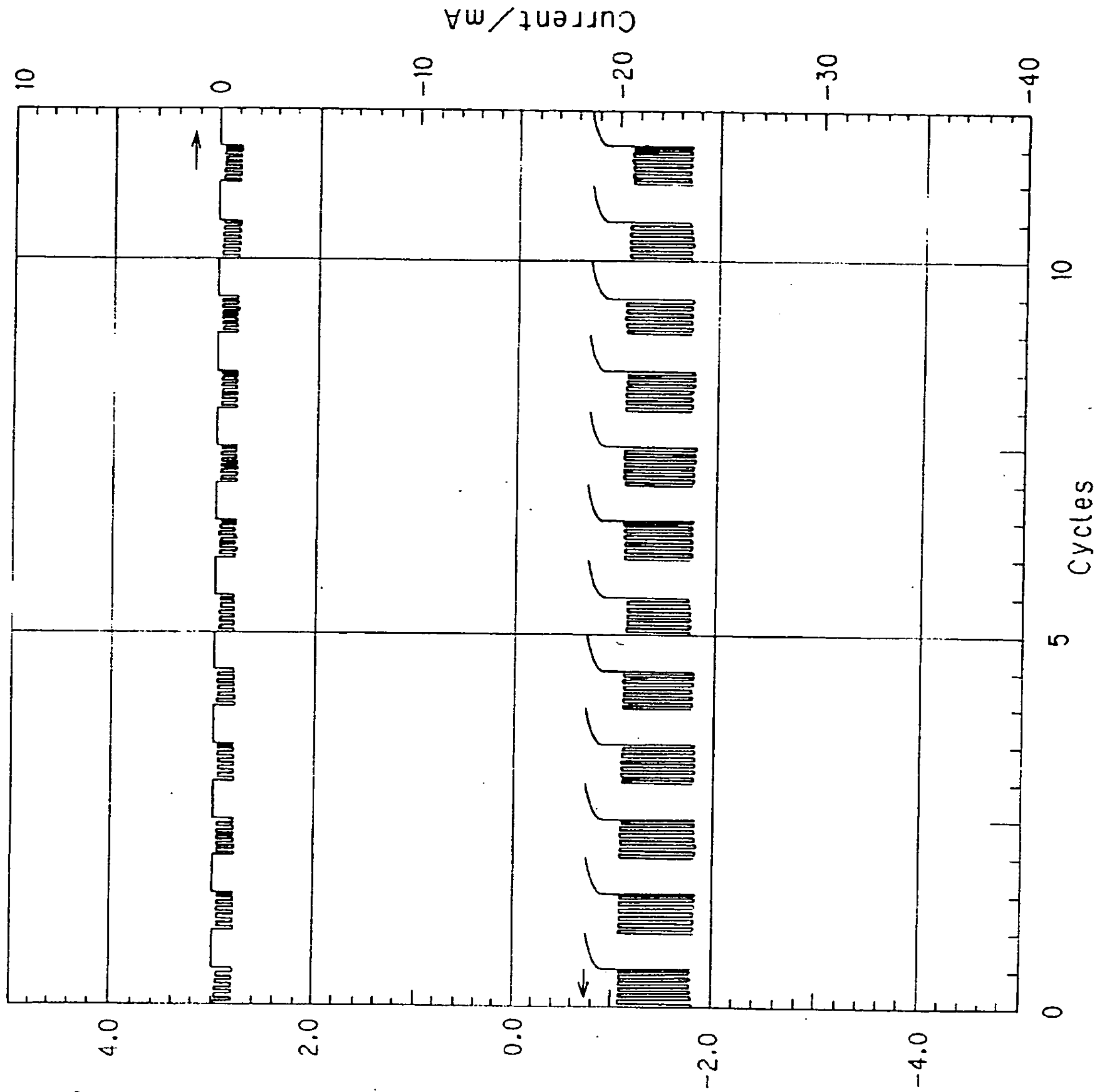

Current/mA
10
0
-10
-20
-30
-40
Cycles
0
5
10
Potential/ vs. Cu/CuSO4
4.0
2.0
0.0
-2.0
-4.0

Fig.4

Fig.5

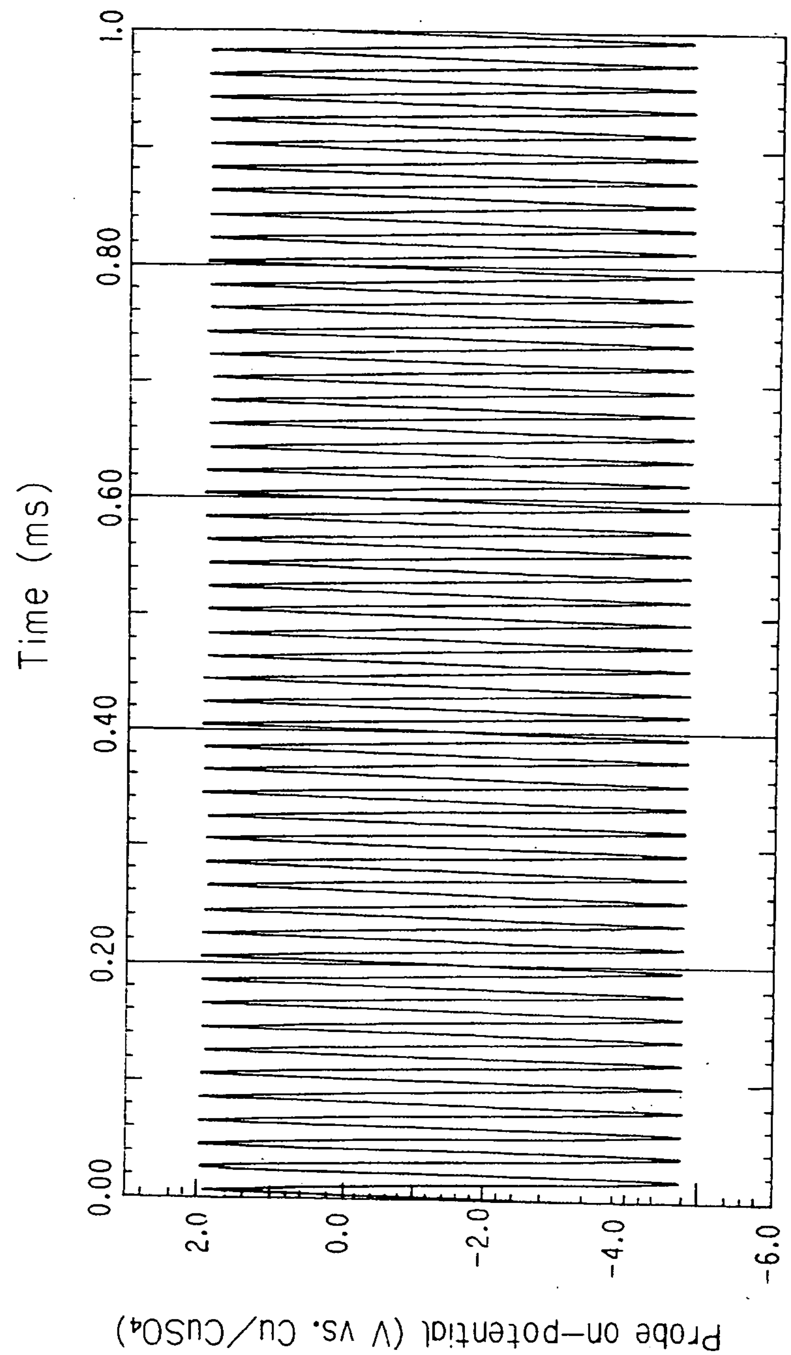

Time (ms)
0.00
0.20
0.40
0.60
0.80
1.0
2.0
0.0
-2.0
-4.0
-6.0
Probe on-potential (V vs. Cu/CuSO4)

Fig.6

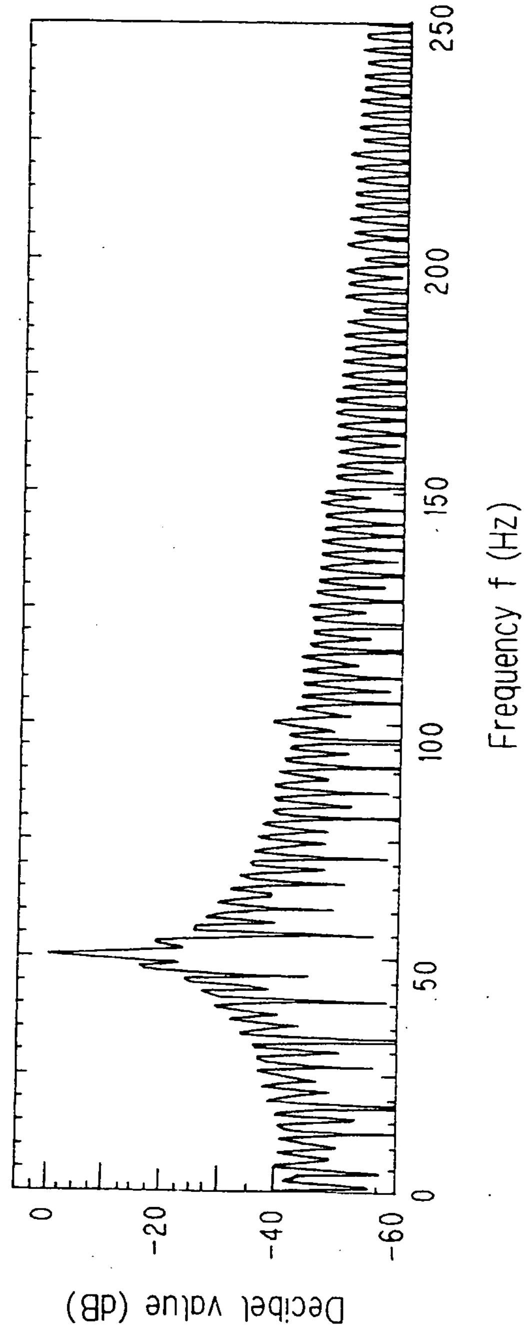


Fig.7

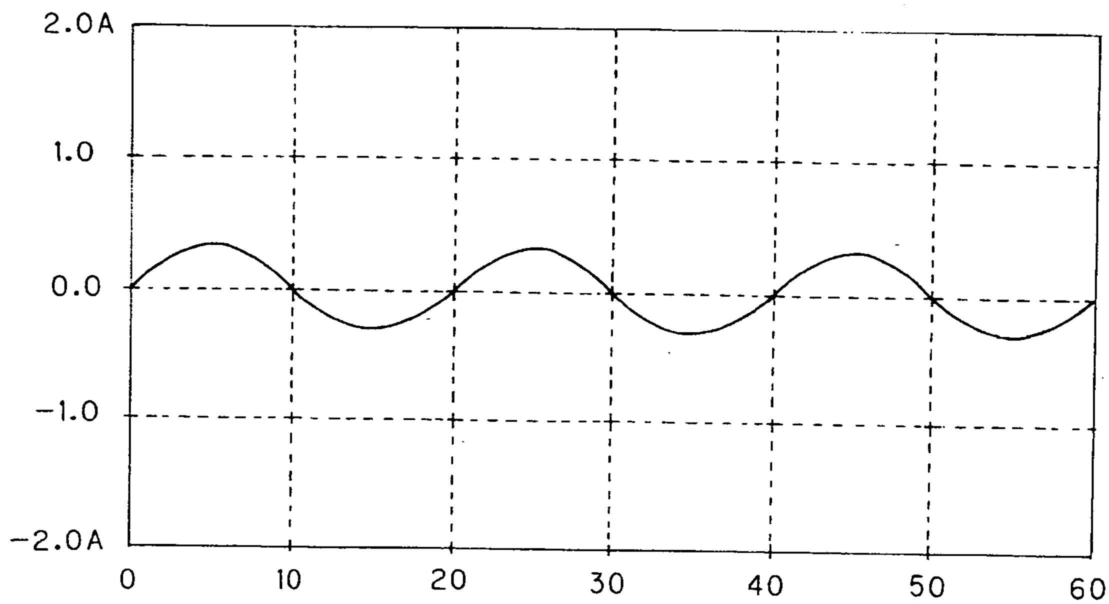


Fig.8

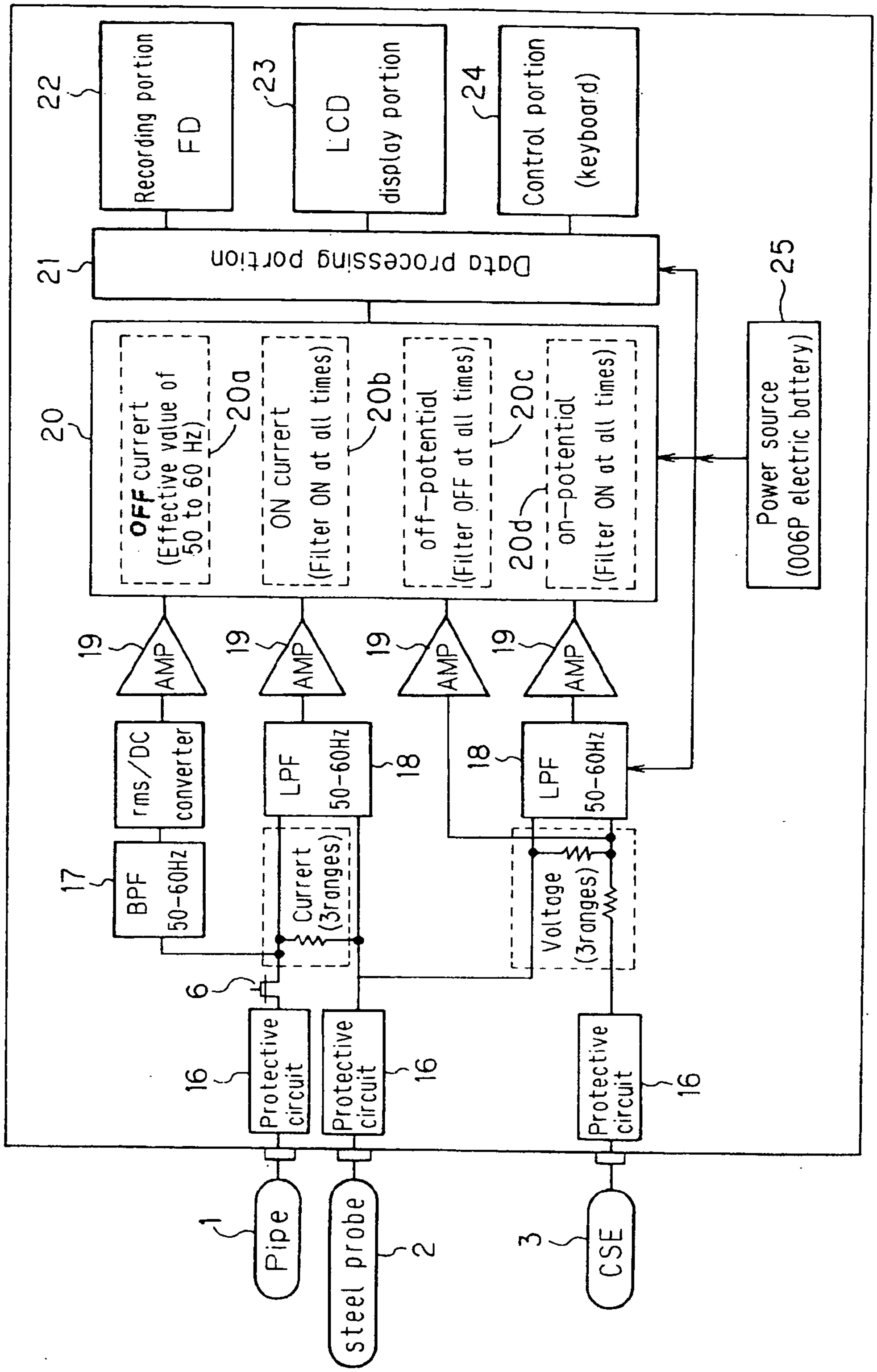
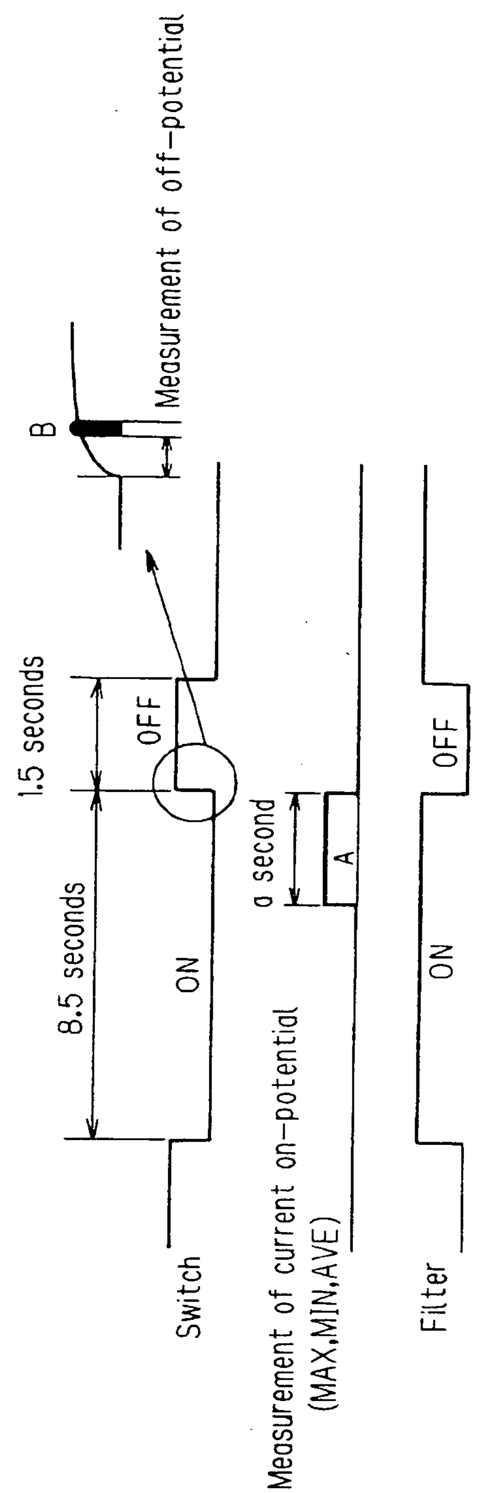

22
Recording portion
FD
23
LCD
display portion
24
Control portion
(keyboard)
21
Data processing portion
20
OFF current
(Effective value of 50 to 60 Hz)
20a
ON current
(Filter ON at all times)
20b
off-potential
(Filter OFF at all times)
20c
20d
on-potential
(Filter ON at all times)
25
Power source
(006P electric battery)
19
AMP
rms/DC converter
LPF
50-60Hz
18
17
BPF
50-60Hz
Current
(3ranges)
Voltage
(3ranges)
6
16
Protective circuit
1
Pipe
steel probe
2
3
CSE

Fig.9



Measurement of off-potential
B
1.5 seconds
8.5 seconds
OFF
ON
a second
A
OFF
ON
Switch
Measurement of current on-potential
(MAX,MIN,AVE)
Filter

Fig.10

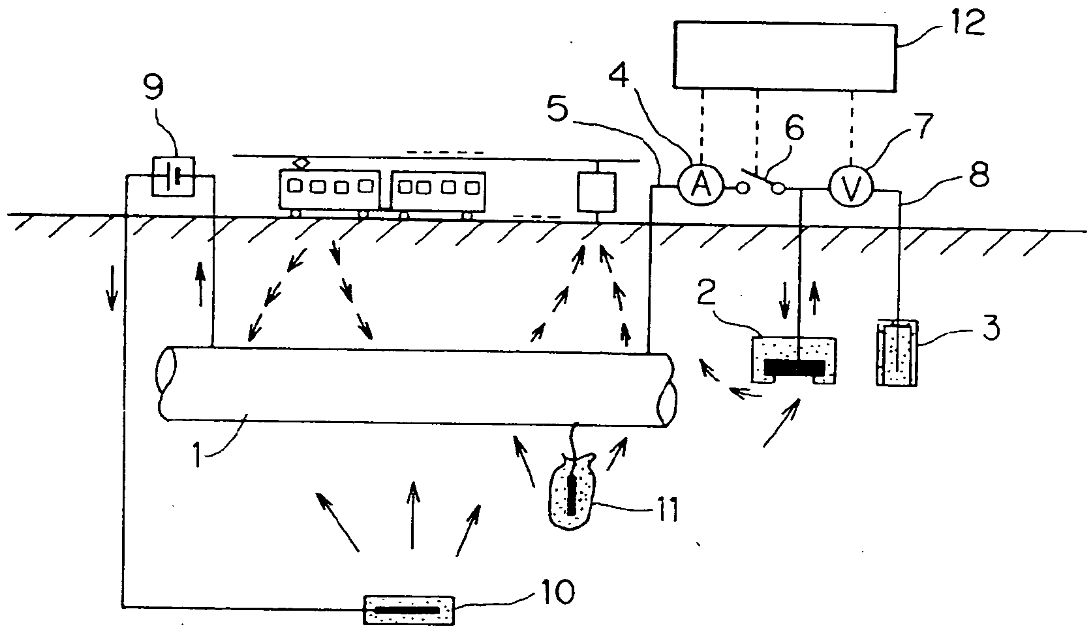


Fig.11

Example of recorder output